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ScienceDirect
Procedia Computer Science 60 (2015) 342 – 351
Procedia Computer Science

19th International Conference on Knowledge Based and Intelligent Information and Engineering Systems

Visualization of key factor relation in clinical pathway

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Abstract

The secondary use of medical data to improve medical care is gaining much attention. We have analyzed electronic clinical pathways for improving the medical process. The analysis of clinical pathways so far has used statistics analysis models, however as issue remains that the order, and multistory spatial and time relations of the each factor could not be analyzed. We constructed an Outcome tree system that shows the greatest significant relation for each factor. The Hip replacement arthroplasty clinical pathway was analyzed by the system, and the outcome variance of the clinical pathway was visualized. The results indicate the path of patient's who have a long hospitalization stay and extracted four critical indicators.

Peer-review under responsibility of KES International

Keywords: Outcome tree; Spanning tree; Clinical pathway; Critical indicator; Hip replacement arthroplasty

1. Introduction

Recently, techniques of data analysis (statistics, visualization, graphing, machine-learning, etc.) have improved, and are being used in various fields. In the medical field, a vast quantity of medical data has accumulated due to the digitalization of medical treatment along with the spread of hospital information systems, and the importance of

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Peer-review under responsibility of KES International
doi:10.1016/j.procs.2015.08.139

medical data utilization is increasing. The secondary use of medical data is expected to improve the quality and the efficiency of medical care, and promote the resolution of medical social issues.

The clinical pathway is a standard medical process for the treatment, test, and operation on the disease of the inpatient, and has progressively become digitized. The Japanese Society for Clinical Pathway[1] promotes the construction of a standard electronic clinical pathway aiming at the standardization of medical treatment, improvement in medical processes, and the spread of the clinical pathway methods by team medical treatment. Specifically, the fundamental outcome called BOM (Basic outcome master) has been defined. When many medical institutions use BOM, the standardization of medical examination spreads, and this enables the analysis and evaluation between medical institutions. The PDCA cycle also is actively used. This is also expected to improve medical management by advancing standardization. We have examined using the clinical pathway data for purpose of extracting CIs (Critical indicators). A CI is the pathway outcome that has the greatest affect on the last outcome (e.g. hospitalization days, discharge destination, outcome, and cost), and is recognized as being sufficiently important.

In the present paper, we constructed an Outcome tree system that applies a spanning tree algorithm, and can visualize and detect as early as possible the causes of long-term hospitalization. We consider important factors from the outcome variance in the clinical pathway that lead to the long-term hospitalization of patients with Hip replacement arthroplasty.

2. Related Work

2.1. Clinical Pathway

There are some previous researches on clinical pathways that study the optimal outcome from medical events and treatment logs[2,3,4], and nursing order[5,6]. Wakata et al.[7] reported analysis conducted using statistical analysis models with the postoperative length of stay as an objective variable, and patients' attributes and clinical pathway outcomes as explaining variables. However an issue remains that the spatial and temporal layer relations of action order, and the importance of pathway outcomes could not be analyzed. Furthermore, the temporal factors of clinical pathways or workflows were considered, however they weren't able to evaluate the medical processes[8,9,10]. In this study, we examine the evaluation of medical processes from the temporal factors of clinical pathways.

2.2. Visualization of Word Relations as a Directed Graph and the Generation of Spanning Trees

Characteristic outcomes of long stay inpatients can be extracted, however it is necessary for the results to be checked by experts to determine if the extracted outcomes are reasonable or not. A Graph of nodes representing the extracted outcomes, and edges representing their relations, are helpful in the interpretation of outcomes. However, a naive co-occurrence graph that connects all the co-occurring outcome pairs would be too complex, because of the large number of edges. There is no appropriate threshold to restrict the number of edges. We can find clusters of outcomes if we draw an undirected graph. However, we cannot see the causal relation of outcomes.

We use the conditional probability and date of the outcomes to formulate causal relation between outcomes of clinical pathways. Then we construct a spanning tree of the target variance using this relation.

Visualization of feature words and their relation is an effective tool for summary of search results and for query expansion. It has been proposed that KeyGraph can be used to capture the structure of documents and core words[11]. The source documents of KeyGraph are expected to be written by an author for some purpose for his/her intension. Thus, the search results of a query are out of scope. Hirokawa et al.[12] proposed the concept graph to generate a hierarchy structure given a query. The concept graph is a directed graph whose nodes are feature words of the search results. Two words are drawn as a directed edge when they have a larger co-occurrence probability than a given threshold. The word with a large frequency is shown in the source of the directed edge and the word with a small frequency is shown in the target of the edge. However, these graphs containing closed loops tend to be hard to show as a tree.

Hirokawa et al.[13] proposed a method to generate a spanning tree where only one node is selected as its parent when a tree is expanded. This algorithm can be applied as long as the words are sorted with some order relation.

Hirokawa et al.[14] visualized a new order relationship of words that combines generality and similarity by applying the spanning tree algorithm.

In this study, to visualize the pattern of long-term hospitalization patients, we analyze pairs of outcome variance data of the Hip replacement arthroplasty clinical pathway, with the postoperative days factor as nodes of the spanning tree. The spanning tree algorithm is applied using the order relation defined as the lexicographic order along with the long-term hospitalization and the similarity of outcomes.

3. Materials

3.1. All-variance Type Outcome-oriented Electronic Clinical Pathway

Since 2004, Kyushu University Hospital has adopted a paper based All-variance type outcome-oriented Clinical Pathway, and was electorized in 2008. At present, 115 different kinds of electronic clinical pathways are employed, and applied to about 5,000 patients each year. An All-variance Type Outcome-oriented Clinical Pathway is expressed as a schedule from hospital admission to discharge compared to the conventional clinical pathway (e.g. sentinel type, gateway type) that list just medical events. It is possible to manage and integrate with medicine, such as monitoring the conditions and assessments of all inpatients, and whether care based on the treatment schedule were conducted or not[15]. Fig. 1 displays the structure of this type of clinical pathway, which consists of a Task layer (daily treatment), Assessment layer (observation), and Outcome layer (daily goal). This unit is the minimum process, multiple outcomes as the scheduled duration of hospitalization. When doctors or nurses in medical practice input tasks, assessment and the upper outcome are evaluated. The variance to outcome is recorded in a clinical pathway when even one doesn't meet the criteria of an assessment layer. Specifically, "0" is set as an achievement, and "1" is set as a variance in the database.

This clinical pathway is recognized as being of very high quality, because the patients' condition is not only input into the chart, but also summarized in free text records. Because it is collected as structured data, the analysis is easier than non-structured data for data extraction.

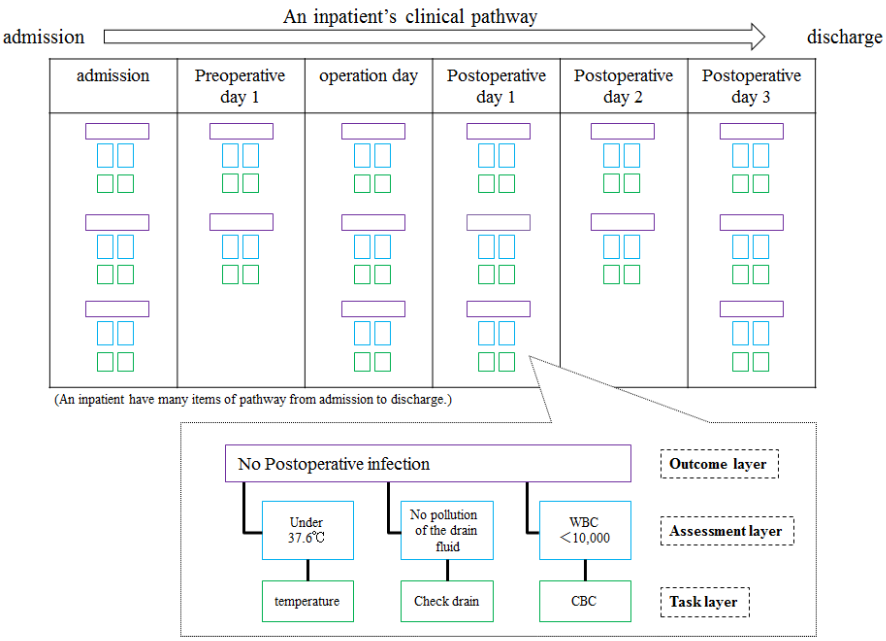

Fig. 1. Structure of All-variance type outcome-oriented clinical pathway.

3.2. Outcome of the Hip Replacement Arthroplasty Clinical Pathway

Hip replacement arthroplasty focuses on the relation between cost, hospitalization days and patient attributes, and pre and postoperative treatment[16,17,18]. Further, it is important to intervene in the timing of postoperative rehabilitation to ensure early discharge. Table 1 shows the pathway outcomes of this case. These pathway outcomes are divided into four categories (C: complication, F: activities of daily living, H: patient condition, K: knowledge understanding). These are scheduled during the duration of hospitalization in Fig. 2. We can see three areas (preoperative, postoperative, after postoperative of day 15) of the pathway outcome. The standard postoperative hospitalization days of the pathway in this case has been set to 27 days.

The present paper analyzed the outcomes of 480 patients who received Hip replacement arthroplasty, carried out in the period of January 2008 to March 2012 in Kyushu University Hospital. A data set was created of the postoperative hospitalization days and outcome for each patient.

Table 1. Outcomes of Hip Replacement Arthroplasty.

Code	Pathway Outcome
C10005	Ambulation
C20001	Respiratory stability
C30005	Vital stability
C40013	Circulation stability
C40019	Awake from anesthesia
C40021	Pain control
C40024	Physical preparation for the operation
C40040	Meal intake
F10002	Understanding the purpose of the admission
F10004	Understanding the purpose of the operation and anesthesia
F20001	Understanding the purpose of the operation result
F30003	Understanding the preoperative orientation
F30004	Understanding the necessary of rehabilitation
H10005	Understanding the contraindications limb of dislocation
H10007	Understanding the life after discharge
H10008	Understanding the condition can be discharged
H10017	Understanding the attention after discharge
H30002	Ambulation
H40003	Respiratory stability
H50002	Vital stability
K20005	Circulation stability
K40002	Awake from anesthesia
K40005	Pain control
K40009	Physical preparation for the operation
K50016	Meal intake
K60014	Understanding the purpose of the admission
K70004	Understanding the purpose of the operation and anesthesia
K70006	Understanding the purpose of the operation result
K70008	Understanding the preoperative orientation

hospitalization days	1st	2nd	3rd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th
Outcome Code	admission	preoperative of day 1	ope day: preoperative	ope day: postoperative	POD 1	POD 2	POD 3	POD 4	POD 5	POD 6	POD 7	POD 8	POD 9	POD 10	POD 11	POD 12	POD 13	POD 14	POD 15	POD 16	POD 17	POD 18	POD 19	POD 20	POD 21	POD 22	POD 23	POD 24	POD 25	POD 26	discharge
C10005				●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
C20001				●	●	●																									
C30005				●	●	●	●	●	●	●	●																				
C40013				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
C40019				●	●	●	●	●	●	●	●																				
C40021				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
C40024				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
C40040				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
F10002											●	●	●	●	●	●	●	●	●	●	●	●	●	●							
F10004																		●	●	●	●	●	●	●	●	●	●	●	●	●	
F20001			●	●	●	●	●	●																							
F30003								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
F30004						●	●		●	●																					
H10005				●	●	●	●	●																							
H10007											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
H10008				●	●	●	●	●	●	●																					
H10017				●																											
H30002				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
H40003	●	●	●																												
H50002					●	●																									
K20005	●																														
K40002		●	●																												
K40005					●	●																									
K40009	●	●																													
K50016					●	●	●	●	●	●	●	●	●	●	●	●	●	●													
K60014					●	●	●	●	●	●	●	●	●	●	●	●	●	●													
K70004																														●	
K70006																									●					●	
K70008																									●						

POD : postoperative of day ● : set outcome

Fig. 2. Scheduled Outcomes of Hip Replacement Arthroplasty.

4. Outcome Tree

4.1. Method

A search engine was constructed from the observation items (outcome) that were evaluated from admission to discharge together with the date as one of the attributes that represents each patient. The patient's postoperative hospitalization days was also added to the index as an attribute. In this search engine, if the postoperative hospitalization length search condition is given, it will search for a list of patients with hospitalization days longer than the specified period. In this paper, the search criteria for patients that stayed for 28 days or more was used to determine a list of patients with a long-term pattern so that the standard postoperative hospitalization length is 27 days.

Then, we constructed a graph showing the relationship of each attribute and the common attributes of patients (outcome variance). First, all of the outcome variance attributes that appear in the search results are sorted in lexicographic order of the similarity and postoperative hospitalization days, and the top K outcomes (o) with days (d) $\{od_1, od_2, ..., od_K\}$ are extracted. Second, the similarity of the search conditions o and query (q) represented by sim (q, o), was evaluated by the Jaccard index as follows (1).

$$sim(q, o) = p(q \times o) \,/\, (p(q) + p(o) - p(q \times o)) \tag{1}$$

$p(q \times o)$ is the number of patients that satisfy the attributes of both q and o, $p(q)$ is the number of patients that satisfy the attributes of q, and $p(o)$ is the number of patients that satisfy the attributes of o (1). Further, $sim(q, o_1) < sim(q, o_2)$ is defined as (2) or (3).

$$sim(q, o_1) < sim(q, o_2) \quad (2)$$

$$sim(q, o_1) = sim(q, o_2) \text{ and } d_1 < d_2 \quad (3)$$

Then, with od_1 as the root of the tree, the tree will expand in the order of od_2, od_3, … When a tree that contains the outcomes to $od_{(i-1)}$ is obtained, the node $od_{(i)}$ is connected to the node with the greatest similarity in od_1, …, $od_{(i-1)}$, except when the similarity is less than the threshold. Further, it will be excluded if the number of results of an AND search of all of the outcomes on the path from the root to $od_{(i)}$ are less than a threshold (least frequency).

4.2. Outcome Tree System

We constructed an Outcome tree system based on the method described as above. Fig. 3 shows the system's general settings: database, threshold between nodes, least frequency of node, horizontal or vertical (form) image aspect, word in node (code). Then, we can search by criteria and evaluate the results of maps quickly. It is also easy to evaluate by color using the four outcome categories (Complication: blue, Activities of daily living: green, Patient condition: yellow, Knowledge understanding: purple).

Furthermore, we set two databases which consist of the outcome up to postoperative days of 27 (POD 27) and 14 (POD 14). POD 27 is the standard postoperative hospitalization, and POD 14 is set for the purpose of extraction of some factors long-term hospitalization early. Each node shows the number of patients with the variance that satisfies all conditions, pre-postoperative days, and outcome code.

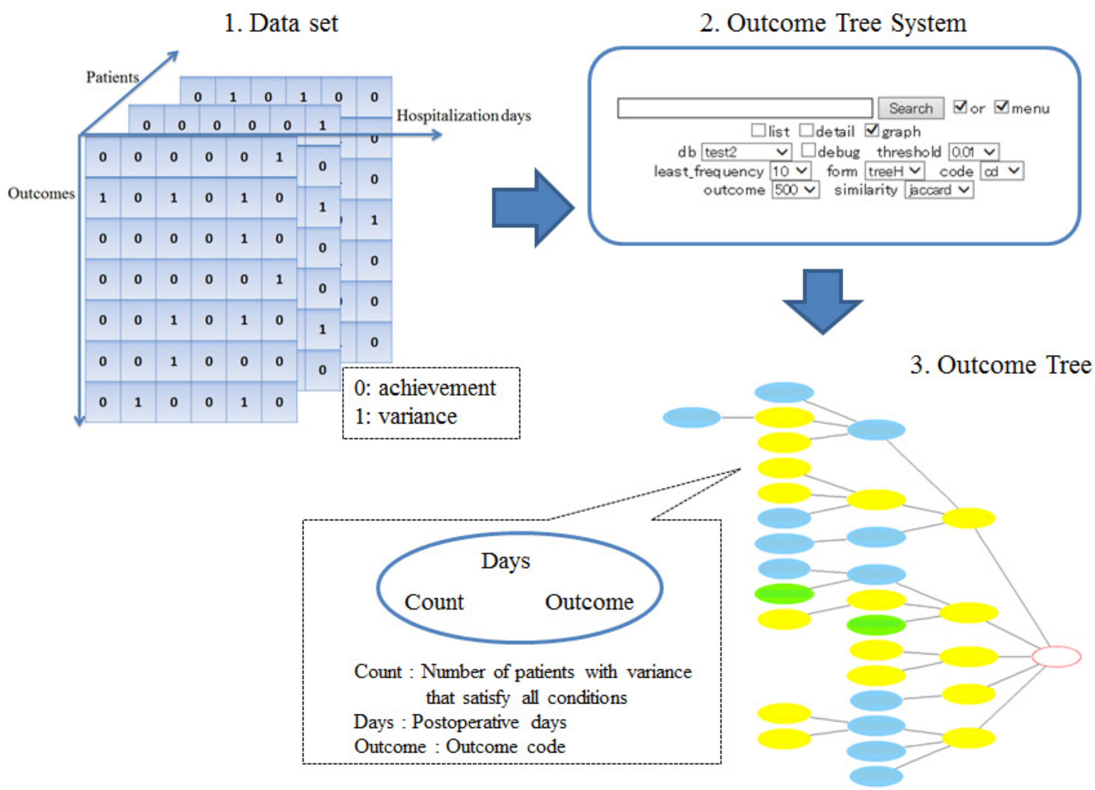

Fig. 3. Concept of Outcome tree system.

5. Result

The system was set to a threshold of 0.01, a least frequency of 10, and the red line represents the path of more than 10% of patients by the third hierarchy. There are 236 patients who stayed longer than the standard hospitalization days (27 days). Fig. 4 shows a map of up to POD 27, and Fig. 5 shows a map of up to POD 14.

In the case of POD 27,

- Postoperative: H10005 (Respiratory stability), POD 1: H10005 (Respiratory stability), POD 2: H10008 (Circulation stability) : 23 patients
- Postoperative: H10005 (Respiratory stability), POD 1: H10005 (Respiratory stability), POD 3: C40024(no problem in wounded area): 26 patients
- Postoperative: H10008 (Circulation stability), POD 1: H10005 (Respiratory stability), POD 3: H10008 (Circulation stability): 25 patients
- POD 1: H30002 (Pain control), POD 7: H30002 (Pain control), POD 8: H30002 (Pain control) : 24 patients
- POD 1: H30002 (Pain control), POD 8: H30002 (Pain control), POD 9: H30002 (Pain control) : 27 patients

In the case of POD 14,

- POD 1: H10005 (Respiratory stability), POD 3: C40024(no problem in wounded area), POD 4: C40024(no problem in wounded area): 27 patients

The common outcomes of POD 27 and of POD 14 are “POD 1: H10005 (Respiratory stability)”, “POD 3: C40024 (no problem in wounded area)”. It appears there are four kinds of outcome on red lines that “H10005 (Respiratory stability)”, “H30002 (Pain control)”, “H10008 (Circulation stability)”, “C40024 (no problem in wounded area). Further, there are many F30003 (Walk rehabilitation is favorable) in POD 27 more than POD 14. In category of outcome, many Complication (blue) and Patient condition (yellow) were extracted, but few Knowledge understanding (purple).

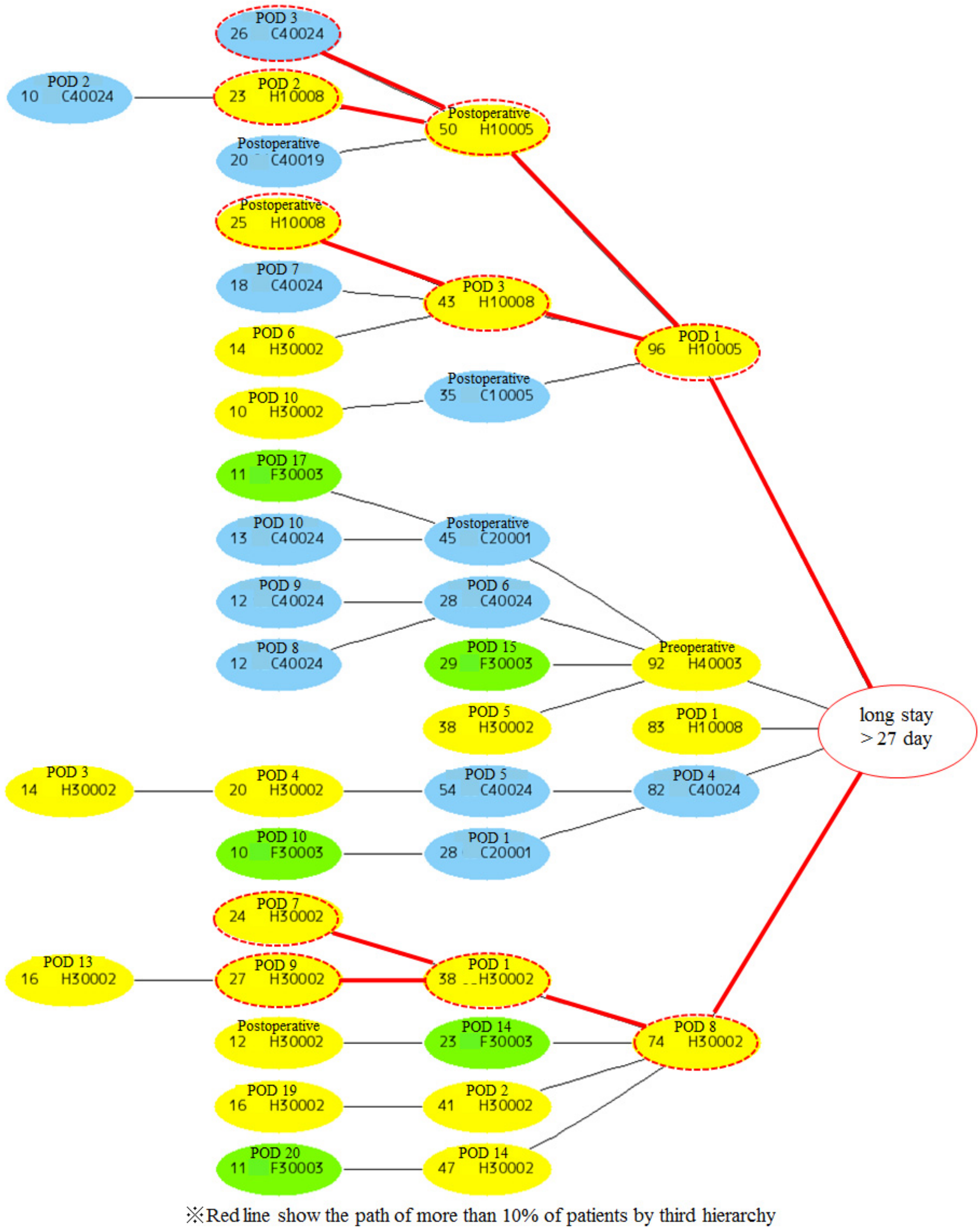

Fig. 4. Outcome tree of outcome variance up to POD 27.

Fig. 5. Outcome tree of outcome variance up to POD 14.

6. Conclusion and Future Work

The relation of long stay inpatients and outcome variance of the All-variance Type Outcome-oriented Clinical Pathway was visualized in an Outcome tree system. Furthermore, this system can show the number of patients related to an outcome variance including the time factor. The reason that it can be expressed like this is because the All-variance Type Outcome-oriented Clinical Pathway has accumulated data correctly and in quantities. The long-term hospitalization of Hip replacement arthroplasty patients is particularly affected by the postoperative outcome variance of Respiratory stability, Pain control, Circulation stability, no problem in wounded area. We extracted four factors as CIs. Furthermore, this result could support medical staff in predicting long stay inpatients so that some factors at a relatively early stage could be found.

For the intervention timing of postoperative rehabilitation, many of the outcomes of rehabilitation appeared in POD 27. It is considered that the variance of rehabilitation immediately after an operation has little affect on the long-term hospitalization, so it cannot be evaluate as a CI. It may also depend on the volume of data in the system, which could explain why POD 14 was not extracted as well as POD 27.

This system achieves the solution to the issue of the order, spatial and time multistory relations of the pathway outcomes. Therefore, we can understand reasonably that specific patient distributions and variances occur in timing, consider these changes, branch, add, and except outcome in the clinical pathway. However, this time we only analyzed long-term hospitalization inpatients. We plan to analyze the standard and short-term hospitalization inpatients to compare the distribution of the outcome variance for each pattern. This system can analyze other cases if the data set is prepared, and can compare between medical institutes. Our goal is that these results will be given as feedback to medical practices for the improvement of medical processes.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 24500176 and 15H02778.

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